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Late Ordovician shelly faunas from Jämtland: palaeocommunity development along the margin of the Swedish Caledonides

PETER DAHLQVIST, DAVID A.T. HARPER & LINDA WICKSTRÖM

Late Ordovician shelly faunas occur at several localities in the Östersund area of Jämtland (Sweden) and developed against a background of intense and rapid global climate change. In the eastern part, approximately in the middle parts of the Kyrkås Quartzite, and in the western part in the uppermost Kogsta Siltstone changes in faunas and sedimentary patterns provide regional evidence of these global events. In both areas the faunas occur in shale and siltstone facies and are used to effect correlations between the eastern and western parts of the region, which show major differences in facies development. These sub-basins, situated on the margins of a developing mountain belt, reacted differently to global signals providing further evidence of the heterogeneous responses to climate change at the end of the Ordovician Period. • Key words: brachiopods, *Hirnantia* fauna, Hirnantian, Jämtland, Late Ordovician, Caledonides, palaeocommunity.

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The end Ordovician marked one of the three greatest Phanerozoic extinction events in the history of life (Bambach 2006). An icehouse interval (Brenchley *et al.* 1994, Saltzman & Young 2005) promoted global cooling and glacio-eustatic sea-level fluctuations that significantly changed global biogeographical and depositional patterns (Brenchley *et al*. 2006). Virtually every section with marine sediments, deposited above storm-wave base, records a regression near the end of the Ordovician and a subsequent transgression within the terminal stage of the system, the Hirnantian (*e.g.* Cocks & Rickards 1988, Sheehan 1988). The Jämtland area is developed along strike from the Oslo Region (Brenchley & Cocks 1982), displays a similar range and diversity of Upper Ordovician-Lower Silurian facies on the edge of the Baltic craton and is partitioned into a set of small basins. However its situation within the Lower Allochthon of the developing Caledonide mountain belt adds a further tectonic dimension to an already complex mosaic of facies. Dahlqvist & Calner (2004) and Dahlqvist (2004) have recently demonstrated the same patterns of sea level change in the sedimentary development of this part of Caledonian foreland basin as elsewhere in the world. The glacio-eustatic sea-level changes affected the ocean circulation (Sheehan 2001), which together with cooling and a restriction of habitat space on the shelves had a profound impact on marine faunas leading to a mass extinction, when about 85% (Jablonski 1991) of marine species became extinct. Currently the mass extinction is partitioned into two biotic events: the first event occurred at the beginning of the glaciation and is associated with the first regressive phase (latest Rawtheyan–early Hirnantian) of the glaciation, while the second event is correlated with the end of the Hirnantian glacial interval (mid-late Hirnantian) and the subsequent transgressive phase (Sheehan 2001). These extinction events approximately coincide with the lower and upper boundaries of the *N. extraordinarius* Zone. Between these crises a brachiopod community termed the *Hirnantia* fauna characterized most shallow-marine settings at temperate and subtropical latitudes. This fauna, first formally named by Temple (1965), was mainly a cold-water fauna, of near cosmopolitan distribution, which makes it of great importance for both inter- and intra-basinal correlation (*e.g.* Rong & Harper 1988, 1999; Cocks 1988; Owen *et al.* 1991; Chen *et al.* 2000; Rong *et al.* 2002). Nevertheless, recent studies (*e.g.* Harper & Rong 2008) have demonstrated a significant heterogeneity through the event; not all basins reacted in the same way and there was a considerable range of community associations within the *Hirnantia* fauna (Rong *et al.* 2008a).

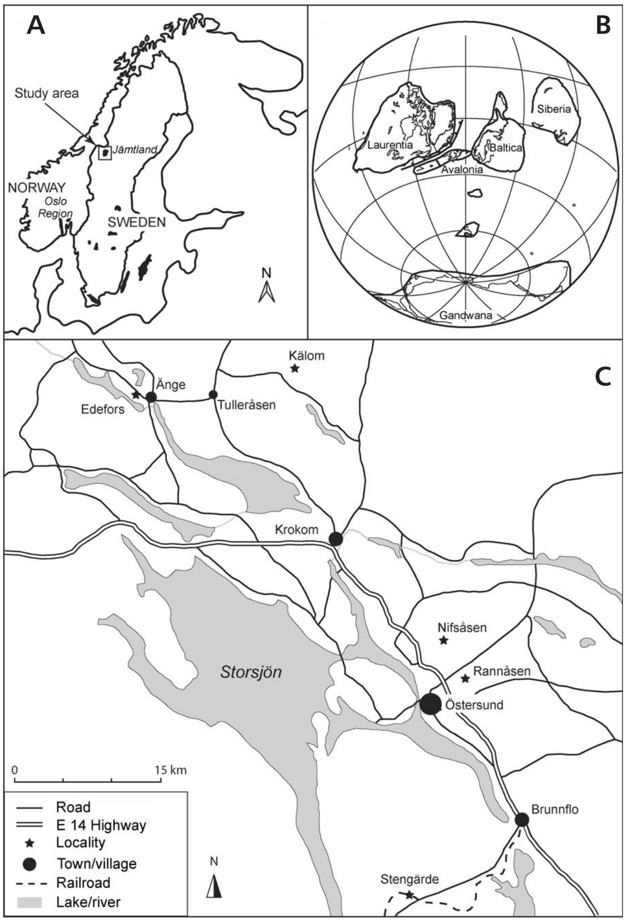

Figure 1. Map of Scandinavia, palaeogeographic setting, and a map of the investigated area. • A – the main Ordovician and Silurian outcrop areas in Sweden and Norway. • B – Ashgill-Llandovery (*ca* 443 Ma) palaeogeography (modified from Torsvik 1998). • C – map of the Östersund/Lake Storsjön area in Jämtland.

The aim of this paper is to present the Hirnantian shelly faunas from Jämtland, document their composition and diversity and relate their development to the ambient climatic change during the later Ordovician. These data are combined with other available biostratigraphical data and previous sedimentological interpretations, to achieve a more accurate picture of the Late Ordovician depositional patterns along the margin of the emerging Caledonian mountain belt in the Jämtland basin.

The Jämtland area

The Jämtland area is situated in central Sweden (Fig. 1A), which now forms a part of the Baltic shield. During the late Ordovician, Baltica was situated within southern tropical latitudes (Torsvik 1998; Fig. 1B). Early Palaeozoic sediments were deposited in a foreland basin extended along the western margin of the Baltic craton. Upper Ordovician rocks are scattered throughout the Östersund-Lake Storsjön area (Fig. 1C), where the uppermost Ordovician strata are represented by three formations: the Kogsta Siltstone followed by the Ede Quartzite in the west and the Kyrkås Quartzite in the east. Late Ordovician basin development in Jämtland has been recently investigated providing a substantial amount of new data on this critical area. Sedimentological research on the Upper Ordovician-Lower Silurian Jämtland succession, including biostratigraphically important data includes work by Cherns & Karis (1995), Dahlqvist (2004), Dahlqvist & Calner (2004), Dahlqvist & Bergström (2005), Dahlqvist *et al.* (2006), and Mötus (2004). Nevertheless, apart from some brief references in the literature (*e.g.* Bergström 1968) data on the important shelly faunas from this area are sparse. A résumé of the upper Ordovician-Lower Silurian succession in Jämtland is presented below.

Lower-Upper Ordovician (middle Caradoc) strata reflect palaeodepth-related differences between the eastern and western part of the Jämtland basin (Karis 1998, p. 165). The eastern area was dominated by shallow-water carbonate deposition, whereas in the western area, mud and turbidite deposits accumulated in deeper water.

A siltstone facies (the Kogsta Siltstone) marks the start of more uniform deposition over large areas of the basin. The base of the Kogsta Siltstone is dated by graptolites of the *Dicranograptus clingani* Biozone. The highest fossils occur a few decimetres below the contact with the overlying Ede Quartzite. Biostratigraphic data from the uppermost metres of the Kogsta Siltstone are discussed in this paper. The Kogsta Siltstone consists of dark grey to black shale interbedded with thin to medium bedded siltstones. The Kogsta Siltstone was deposited in an offshore environment. The upward increase of silt and the appearance of primary sedimentary structures indicate a minor increase in depositional energy, reflecting a slight shallowing.

Above the Kogsta Siltstone, depositional patterns become more complex, with the deposition of the Kyrkås Quartzite in the western part of the region and the Ede Quartzite in the eastern part.

The Kyrkås succession contains approximately 90 m of siliciclastic rocks. Two sequences are present, each showing shoreline progradation, commencing with offshore deposited mud and ending with mid-upper shoreface sand (Dahlqvist 2004). The horizon yielding fossils is situated approximately in the middle of the formation, just below a conspicuous 0.75 m thick bed, termed the Rusty Marker Bed (RMB, Dahlqvist 2004). The RMB occurs in each section at several localities and most probably was a synchronous deposit, which makes it possible to use as a lithological marker horizon. Graptolites, including *Normalograptus persculptus* have been found approximately 2–3 m above this siltstone and were referred to the *Persculptograptus persculptus* Biozone within the uppermost Hirnantian (highest Ordovician) by R.B. Rickards *in* Cherns & Karis (1995).

Table 1. Brachiopods (b) and trilobites (t) recovered from the different localities investigated in this study; elsewhere on Baltica their occurrences in Västergötland (F) and Oslo (G) are indicated. Faunal elements with an asterisk* are typical elements of the *Hirnantia* fauna according to Rong & Harper (1988) and Owen *et al.* (1991). Abbreviation: A – Edefors, B – Stengärde, C – Kälom, D – Nifsåsen, E – Rannåsen, F – Västergötland, G – Oslo.

Species	A	B	C	D	E	F	G
* *Hirnantia sagittifera* (b)		×				×	×
* *Dalmanella testudinaria* 2 (b)	×		×		×	×	×
* *Eostropheodonta hirnantensis* 2 (b)					×	×	×
* *Cliftonia* sp. (probably *C. psittacina*) (b)		×				×	×
* *Kinnella*? *kielanae* 2 (b)					×	×	×
Leptaena rugosa (b)		×				×	×
Orbiculoidea sp. cf. *radiata* 2 (b)					×		
Orbiculoidea concentrica (b)		×					
Leptaenopoma trifidium 1, 2 (b)					×	×	×
* *Brongniartella platynota* 1, 2 (t)		×			×		
* *Dalmanitina* (*M.*) *mucronata* 1, 2 (t)	×	×		×	×		
'*Aegiromena*' sp. (b)	×		×	×			
draboviid? (b)	×		×			×	×
Leptaena sp. (b)				×	×		
Dysprosorthis sp. (b)				×	×	×	×
strophomenid (b)				×	×		
orthid (b)				×	×		
Illaenus? sp. (t)					×		
proetid (t)	×		×				

The Lower Ede Quartzite (0.9–5 m) has not yielded fossils but based on sedimentology it is interpreted as the latest Ordovician glacio-eustatic low-stand and thus is of Hirnantian age (Dahlqvist & Calner 2004). This lower part was deposited in a shoreface environment during forced regression (Dahlqvist & Calner 2004). The Upper Ede Quartzite (*ca* 4 m) has yielded a conodont fauna of the early-mid Aeronian *Pranognathus tenuis* Zone (Dahlqvist & Bergström 2005). The upper part consists of thin bedded, mixed carbonate-siliciclastic sediments deposited in a wave dominated proximal environment (conodont biofacies suggesting BA 1–2, Dahlqvist & Bergström 2005). The contact between the Lower and Upper Ede Quartzite, probably includes the Ordovician-Silurian boundary interval, appears to be an unconformity associated with a significant hiatus that excludes some or all of the uppermost Hirnantian and at least the Rhuddanian Stage (Dahlqvist & Calner 2004, Dahlqvist & Bergström 2005).

To conclude, the Ede and Kyrkås quartzites demonstrate a difference in depositional patterns in the eastern versus the western part of the area. The eastern area shows two regressive events of similar magnitude (with two sequences within the Kyrkås Quartzite, Dahlqvist 2004) while the western area shows one small (within the Kogsta Siltstone) followed by one major regressive event (lower Ede Quartzite; Dahlqvist & Calner 2004). The investigated Hirnantian faunas occur, in both the eastern and western areas, a few metres below evidence of the second regressive event. Consequently, the biostratigraphical data available suggest that the observed regressive successions could be related to the Late Ordovician glacio-eustatic sea-level changes but the water-depth signal has been locally modified. The differences in depositional patterns, lateral changes in response to the eustatic movements, are probably related to a palaeoslope, which was inclined from the eastern part, basinward towards the west. Dahlqvist & Bergström (2005) suggested that the migration of a peripheral bulge over the Ede area could be a possible cause for parts of this depositional pattern.

Transgressive strata from the postglacial sea-level rise are lacking in the eastern area due to later erosion, the Kyrkås Quartzite being the youngest preserved strata, whereas Early Silurian (but not earliest) mixed carbonate-siliciclastic deposits blanketed the unconformity in the west (Dahlqvist 2004, Dahlqvist & Calner 2004, Dahlqvist & Bergström 2005). This was followed by a period of more uniform deposition, the Lower Silurian Berge Limestone and the succeeding Bångåsen Shale.

Materials and methods

The faunas discussed in this paper have been collected at different localities by different geologists during the last decades, numbers given within brackets refer to numbers given later in the text and on the figures; Edefors: (1) P. Dahlqvist (this paper); (2) M.G. Bassett and L. Karis (unpublished collection); Stengärde: (3) J. Bergström (1968); Kälom: (4) L. Wickström and P. Dahlqvist (this paper); Nifsåsen: (5) P. Dahlqvist (this paper) and Rannåsen: (6) P. Dahlqvist (this paper); (7) L. Liljedahl and K. Larsson (unpublished collection); and (8) P. Thorslund (1960).

All of the faunas have been sampled from the shale-siltstone facies. The strata of the Kogsta Siltstone are however more shaly than the interval yielding fossils within the Kyrkås Quartzite. The fossils are poorly preserved or dissolved, leaving only moulds. The main components of the faunas and their sampling levels are shown in Figs 2 and 3. Correlation of the various sections is a presented in Fig. 4. Additionally, the brachiopods and trilobites recovered from each locality are given in Table 1.

Localities and faunas

Edefors (Kogsta Siltstone), Fig. 2A. – This is the type locality of the Ede Quartzite (7040198/1411158, Swedish National Grid). Several exposures of the Kogsta Siltstone, Ede

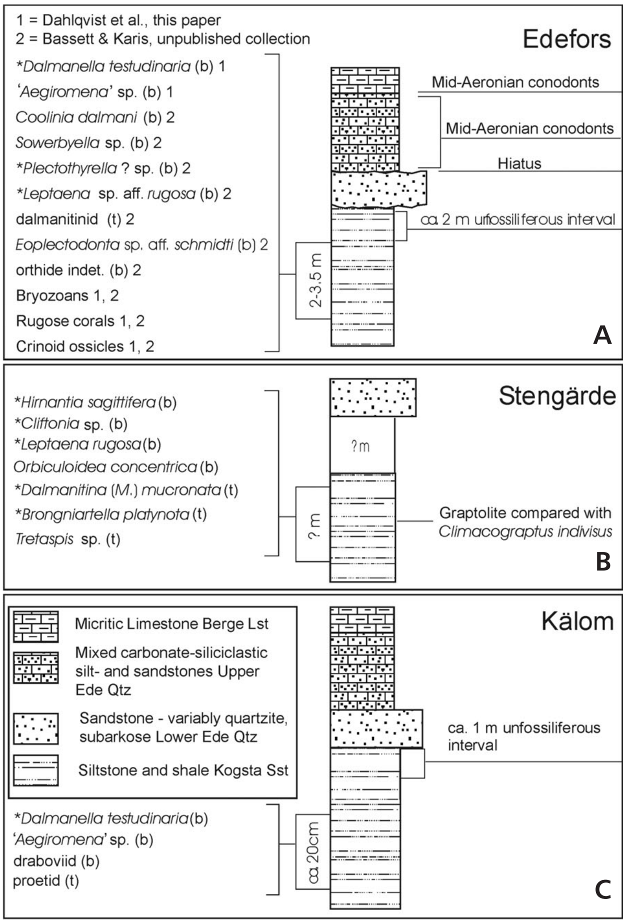

Figure 2. Localities, successions and faunal elements from the Kogsta Siltstone. A – Edefors, B – Stengärde, C – Kälom; t – trilobite, b – brachiopod. Additional biostratigraphical data from Dahlqvist & Bergström (2005; conodont data in fig. 2a). Faunal elements with an asterisk* are typical elements of the *Hirnantia* fauna according to Rong & Harper (1988) and Owen *et al.* (1991).

Quartzite and Berge Limestone crop out on the slopes of a hill *ca* 1 km SE of Offerdal church. The entire Edefors succession is described in detail in Dahlqvist & Calner (2004).

Dahlqvist, this paper (1): Several smaller exposures were sampled along the south-facing hillside. The faunas were collected approximately 2–3.5 m below the contact with the overlying Ede Quartzite. The distance to this contact is approximate because of the nature of the outcrops, scattered exposures in talus accumulations.

This fauna is overwhelmingly dominated by the species of a new brachiopod taxon, very similar to *Aegiromena* (commonly occurring in concentrations, subsequently referred to '*Aegiromena*') and *Dalmanella testudinaria* (see Jin & Bergström 2010 for a revision of this important species) but it also contains the trilobite *Dalmanitina* (*Mucronaspis*) *mucronata*, rugose corals and crinoid fragments. This deep-water facies is either of latest Rawtheyan or early Hirnantian age.

Reference samples are stored at the Department of Geology, Lund University, Sweden.

Bassett & Karis, unpublished (2): The fauna was collected at approximately 4.5 m below the contact with the Ede Quartzite and includes the following: *Coolinia dalmani*, *Plectothyrella*? sp., *Leptaena* sp. [?aff. *rugosa*], indeterminate dalmanellids, an indeterminate orthid [coarse ribbed – similar to either *Sulevorthis* or *Nicolella*], *Eoplectodonta* aff. *schmidti, Sowerbyella* sp., *Dalmanella* sp. [?cf. *testudinaria*], 'dalmanitinid' trilobites, solitary rugose corals, crinoid stems, and indeterminate bryozoans (M.G. Bassett, pers. comm. 2004). This fauna is most probably of Hirnantian age.

Stengärde (Kogsta Siltstone), Fig. 2B. – This is a railway section (6988632/1440559, Swedish National Grid) located ca 300 m N of the railroad bridge along the track. This section exposes only the Kogsta Siltstone, and there is no sign of any succeeding quartzite. The Ede Quartzite can however be found in the area. The thickness of the strata is difficult to measure due to folding. The Kogsta Siltstone here contains only a few calcareous nodules.

Bergström 1968 (3): Bergström (1968) collected a few specimens of brachiopods and trilobites from a mudstone bed at Stengärde that was correlated with the Dalmanitina Beds, within part of the Kogsta Siltstone. Since the Ede Quartzite is not present at this locality, the precise stratigraphical position of the collection is uncertain.

The fauna includes the brachiopods *Cliftonia* sp. (probably *C. psittacina*), *Hirnantia sagittifera*, *Leptaena rugosa*, *Orbiculoidea concentrica* and the trilobites *Dalmanitina* (*Mucronaspis*) *mucronata*, *Brongniartella platynota*. Re-examination of the material during this study was unable to confirm the presence of *Hirnantia sagittifera*. Nevertheless, this fauna is almost certainly of Hirnantian age.

The fauna shows similarities to the *Hirnantia* Association found in the central Oslo Region (Brenchley & Cocks 1982), but lacks some of the key elements of the Norwegian association such as *Dalmanella testudinaria*, *Hindella cassidea*, and *Eostropheodonta hirnantensis*.

Reference samples are stored in the Department of Geology, Lund University, Sweden.

Kälom (Kogsta Siltstone), Fig. 2C. – Two neighbouring localities (E1425014/N7042266 and E1425617/N7042740) have yielded material. Exposures of the uppermost Kogsta Siltstone, the lower and upper Ede Quartzite and the lowermost Berge Limestone occur in an enclosed pasture approximately 200 m from the road through the village Öster Ulvsås, approximately 6 km from road 340.

Wickström & Dahlqvist, this paper (4): The fauna was collected at two localities. They are similar in composition and were collected approximately 0.5–1 m below the contact to the Ede Quartzite. The siltstone is dominated by

Dalmanella testudinaria and a large species of '*Aegiromena*' commonly occurring in concentrations. Additional elements include a possible draboviid brachiopod and a proetid trilobite. This deep-water facies is of either latest Rawtheyan or early Hirnantian age. Reference samples are stored at the Swedish Geological Survey (SGU), Uppsala, Sweden.

Nifsåsen (Kyrkås Quartzite), Fig. 3A. – The main locality is in Nifsåsen Quarry (701350/144325, Swedish National Grid) is situated *ca* 5.5 km NNE of Östersund, *ca* 2 km NE of the main road (E14). This is a large quarry with near vertical strata in high, steep walls. The entire Kyrkås Quartzite succession was described in detail by Dahlqvist (2004). The Nifsåsen quarry is still in production.

Dahlqvist, this paper (5): The fauna was collected just below a marker bed (the RMB, Dahlqvist 2004) in an interval of about 1 m, at the SW-wall. The investigated fauna includes species of the brachiopods '*Aegiromena*', *Dysprosorthis* sp. and *Leptaena* together with indeterminate orthid and strophomenid shells and the trilobites *Dalamanitina* (*Mucronaspis*) *mucronata*. Additional fossils include bivalves, gastropods, hyolithids, orthocones, and one graptolite. Reference samples are stored in the Department of Geology, Lund University, Sweden.

Rannåsen (Kyrkås Quartzite), Fig. 3B. – The key locality is in Rannåsen Quarry (701020/144425, Swedish National Grid) is located *ca* 2.5 km NE of Östersund, *ca* 1 km E of the main road (E14). The section at Rannåsen is one of the most examined and noted successions in the Jämtland area, *e.g.* Thorslund (1943, 1960), Karis & Larsson (1982), Cherns & Karis (1995) Dahlqvist (2004) and Wickström *et al*. (2007). The Rannåsen quarry is still in production.

Dahlqvist, this paper (6): Fossils were sampled at the NE corner of the quarry in an approximately 1 m thick interval below the RMB.

The investigated fauna includes the brachiopod genera '*Aegiromena*' and the trilobite genera *Brongniartella* and *Mucronaspis*. Reference samples are stored in the Department of Geology, Lund University, Sweden.

Liljedahl & Larsson, unpublished (7): Thirty-two species of invertebrates were recorded from this locality, mostly as *in situ* samples from below the RMB but some from loose blocks. Eighteen species (56%) are molluscs (15 bivalves, 2 cephalopods, 1 gastropod), 8 (25%) are brachiopods (2 nonarticulate, 6 'articulate'), 3 (9%) trilobites and one (3%) graptolite, hyolithid, and tentaculitid, respectively. Bivalves are by far the most dominant faunal element and constitute 47% of the 252 specimens recorded.

The high proportion of articulated bivalves suggests preservation *in situ*. The fauna includes the brachiopods *Eostropheodonta hirnantensis*, *Dalmanella testudinaria*, *Kinnella*? *kielanae*, *Orbiculoidea* cf. *radiata*, and *Leptaenopoma trifidium* [Note: Some authorities have synonymised *Leptaenopoma trifidium* with *Leptaena rugosa*; here we have retained the original identifications by Bergström (1968) where appropriate], the trilobites *Brongniartella platynota*, and *Dalmanitina* (*Mucronaspis*) *mucronata* and the bivalves *Allodesma*? sp., a modiomorphid, *Modiomorpha*? sp., a pterineid, a cyrtodontid, *Cyrtodonta suecica*?, *Palaeonelio* cf. *plana*, *Tancrediopsis*? sp., *Praenucula*? sp., *Sphenotus*? sp., *Praeanomalodonta*? sp., *Colpomya* sp., *Whiteavesia* cf. *cincinnatiensis* and *Cuneamya carpomorpha*. According to John Cope, National Museum of Wales, Cardiff (pers. com.) the bivalves are mostly infaunal taxa, but with some epibyssate benthos and is characteristic of a shallow water shelf assemblage. Reference samples are stored in the Department of Geology, Lund University, Sweden.

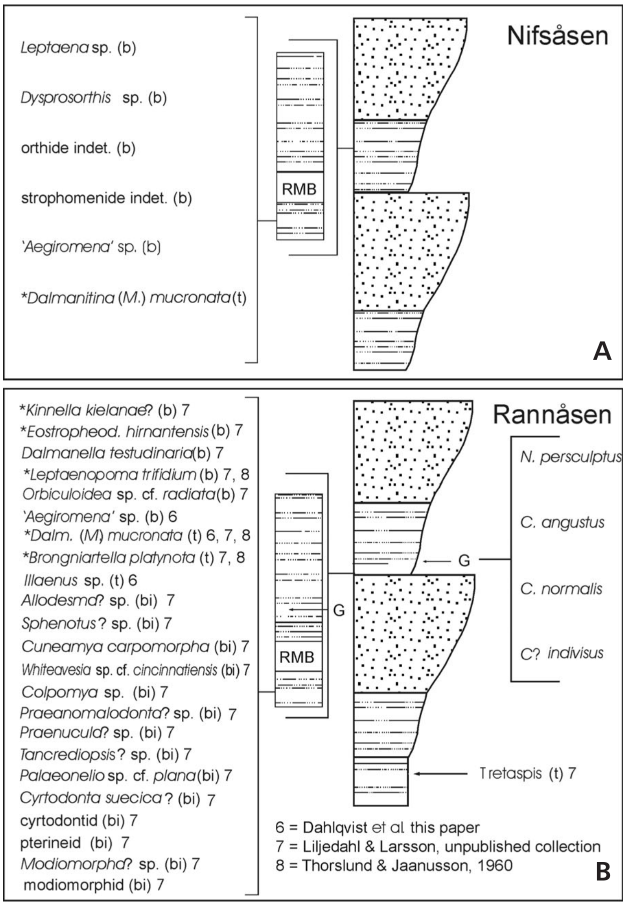

Figure 3. Locality successions and fauna elements from the Kyrkås Quartzite. A – Nifsåsen, B – Rannåsen; t – trilobite, b – brachiopod, bi – bivalve. Additional biostratigraphical data from Cherns & Karis (1995; graptolite data in fig. 3b). Faunal elements with an asterisk* are typical elements of the *Hirnantia* fauna according to Rong & Harper 1988 and Owen *et al.* (1991).

Brenchley & Cocks (1982) recovered a similar fauna from the central Oslo Region that they assigned to their *Trematis*-Bivalve assemblage. This fauna is dominated by modiolopsid bivalves and the large brachiopod *Trematis*

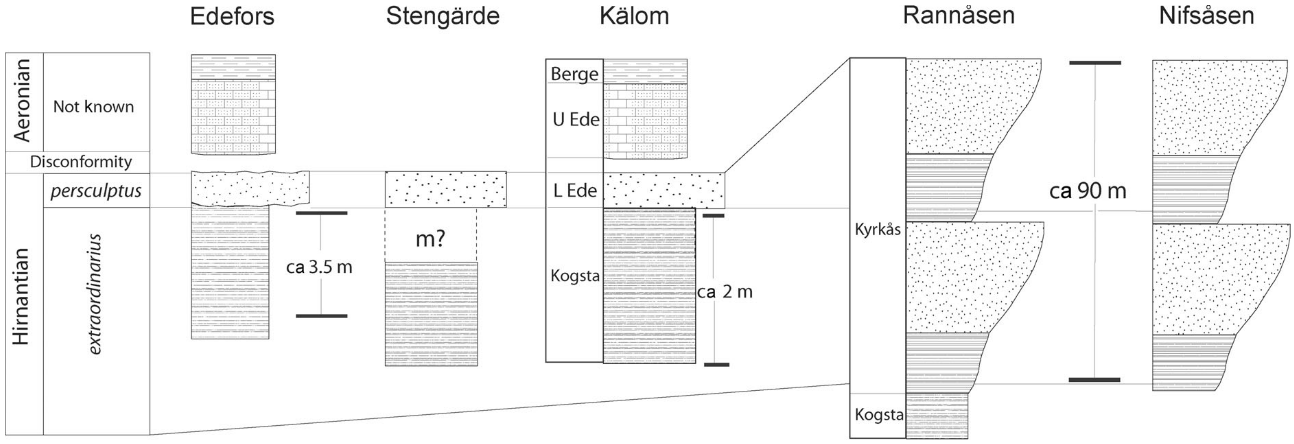

Figure 4. Correlation of the sections at Edefors, Stengärde, Kälom, Nifsåsen and Rannåsen. Based on Dahlqvist (2005, fig. 6).

norvegica, and includes a few specimens of the brachiopods *Hindella cassidea*, *Hirnantia* sp., *Eostropheodonta* sp., *Leptaena* sp. and the bivalves *Pterinea* sp. and *Cuneamya*? sp. This fauna occurs above beds with the *Hirnantia* association at the level where inner shelf mudstone facies passes into the sandy lower shoreface facies. In a recent study of the uppermost Ordovician bilvalves from the Prague Basin Kříž & Steinová (2009) describes two different comunities containing bivalves; the *Modiolopsis* Comunity Group, a low diversified community from coarse storm generated sandstones and, the *Hirnantia saggittifera–Sluha kosoviensis* Comunity Group, a high diversified fauna living in a soft bottom environment with a high organic content. The Rannåsen fauna occupied a more muddy environment, that may explain the differences in composition between this locality and most of the others.

Thorslund 1960 (8): The reported fauna includes the brachiopod *Leptaenopoma trifidum* and the trilobites *Dalmanitina* (*Mucronaspis*) *mucronata*, *Brongniartella platynota* and a species of *Illaenus*. Thorslund (1960) did not mention where he collected the material, but the fauna is probably Hirnantian in age.

Discussion

The faunas can be partitioned into two groups corresponding to an east west transect across the sub-basins (see Fig. 1c). The sections at Edefors and Kälom are dominated by *Dalmanella testudinaria* and a species of '*Aegiromena*' together with the trilobite *Dalmanitina* (*Mucronaspis*) *mucronata*. The occurrences of a possible species of *Plectothyrella* together with *Coolinia dalmani* support a correlation with the Hirnantian rather than the Rawtheyan (upper Katian). Both faunas occur in the siltstones and shales of the upper part of the Kogsta Siltstone and are succeeded by the quartzites of the Lower Ede Quartzite. At Stengärde elements of the *Hirnantia* fauna, including *Hirnantia sagittifera*, *Cliftonia psittacina* together with *Dalmanitina (Mucronaspis) mucronata* and *Brogniartella platynota* occur in siltstones and shales of the upper Kogsta Siltstone.

At Nifsåsen and Rannåsen in the vicinity of Östersund, the fauna occurs just below the RMB within the Kyrkås Quartzite. At Rannåsen the brachiopod assemblage is typified by some key elements of the *Hirnantia* fauna together with a diverse bivalve fauna whereas at Nifsåsen the fauna is much less diverse with only a few brachiopods including *Dysprosorthis* and *Leptaena*.

There are, however, a number of unusual aspects of the Jämtland faunas and their settings. First there is considerable variation in faunal composition in the assemblages over a relatively small area of some 540 km^2. This suggests differences in both water depth and perhaps substrate associated with an uneven seafloor. Second the *Hirnantia* faunas in contrast to many other parts of the world do not appear to occur against a background of substantial regression; the first evidence (in this case forced regression) of major regression occurs above the *Hirnantia* faunas. Dahlqvist & Calner (2004) suggested that both local subsidence and patterns of sediment production and delivery might have been sufficient to mask these global signals of regression and transgression. In the eastern parts of the basin deeper water facies (mid to upper shoreface deposits, Dahlqvist 2004) persist in the Kyrkås Quartzite, probably until the Rhuddanian. In the west, however, shallow water quartzitic sandstone of the Ede Quartzite was deposited during a forced regression. These sediments were followed by emergence and/or non-deposition leading to a hiatus (Dahlqvist & Calner 2004). Dahlqvist & Bergström (2005) suggested that local uplift was associated with the development of a peripheral bulge along this part of the Baltic margin.

Such regional heterogeneity is not unusual along the margins of the Caledonian orogen. Along strike in the Oslo Region there is similar variation. In the central, deeper parts of the Oslo basin, the lower Hirnantian is characterized by at least three, relatively diverse, variants of the typical *Hirnantia* (Kosov Province) fauna; whereas the summit of the Ashgill (Hirnantian) succession contains elements of the mid-Continent (Edgewood Province) in channel fill deposits (Brenchley & Cocks 1982). A relict Ordovician brachiopod fauna persisted during the earliest Silurian in the deeper parts of the Oslo basin (Baarli & Harper 1986). Farther north in the Ringerike district, the Hirnantian is probably missing (Harper, personal observations; Thomsen *et al*. 2007) whereas in the adjacent Hadeland district the Ordovician-Silurian boundary strata are represented by shallow-water, siliciclastic facies with low diversity brachiopod and trilobite faunas (Owen *et al*. 2008). Basement faulting in the Oslo Region, has been invoked to explain the marked variation in local facies patterns associated with the development of the adjacent Caledonian orogen (Bruton & Harper 1988).

Global context of the Jämtland faunas

Initial global reviews of the Hirnantian brachiopod and trilobite faunas (*e.g*. Rong 1984, Rong & Harper 1988, Owen 1986, Owen *et al*. 1991) indicated geographical together with depth and substrate controls on their distributions. Within the Brachiopoda three provinces were established (Rong & Harper 1988): The Bani (high latitude), the Kosov (temperate to subtropical latitudes) and the Edgewood (low latitudes); the typical *Hirnantia* fauna occupied the Kosov Province. Within the Kosov Province there was also a clear depth zonation with the shallow water, nearshore facies dominated by rhynchonellide brachiopods, and the shallow to midshelf depths occupied by associations dominated by species of *Eostropheodonta*, *Hindella* and *Hirnantia* and the deep water by the species of the strophomenide genera *Aegiromena* and *Paromalomena*. These patterns have been largely confirmed by more modern studies (*e.g*. Rong *et al.* 2008a). A cluster analysis (Fig. 5) of a subset of the available dataset of Hirnantian brachiopod faunas (see Rong & Harper 1988, Hammer *et al.* 2001) places the Jämtland faunas with the Kosov Province. Significantly, however, while *Hirnantia* and *Mucronaspis* faunas continued to dominate the western margin of Baltica during the Late Ordovician, elements of the Laurentian Edgewood Province were already present in Östergötland (Rong *et al.* 2008b) and a typical Edgewood fauna occupied latest Ordovician carbonate environments in the Oslo Region (Brenchley & Cocks 1982). Moreover the presence of a taxon closely related to *Aegiromena* confirms the presence of deeper-water facies, mainly siliciclastic, in the Jämtland basins, just adjacent to and partly within the developing Caledonide mountain belt.

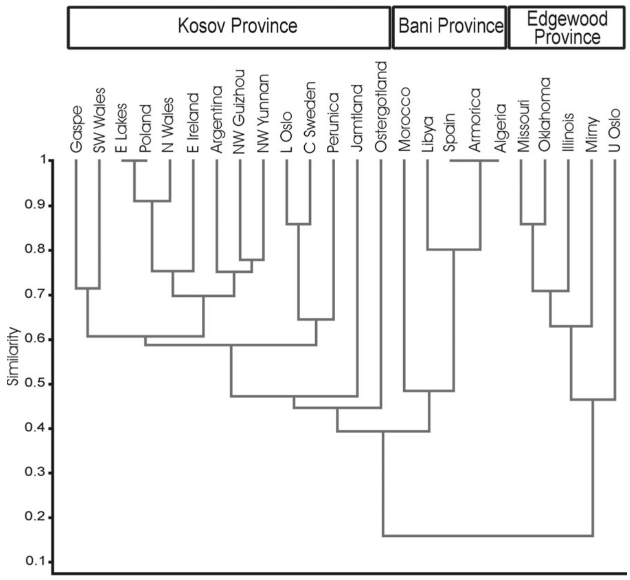

Figure 5. Cluster analysis of a partial dataset of Hirnantian brachiopod global distributions (data modified and updated from Rong & Harper 1988; see also http://folk.uio.no/ohammer/past/study7.html) using Dice coefficient and average weighted pair clustering. The three main Hirnantian provinces are indicated, with the Jämtland faunas associating with the Kosov Province.

Conclusions

New collections and reassessment of existing collections from the Upper Ordovician rocks of the Jämtland area confirm the development of variants of the *Hirnantia* brachiopod fauna on the western edge of Baltica. Most of the taxa are typical of the temperate to subtropical Kosov Province (Rong & Harper 1988). There is nevertheless significant variation in the composition of these faunas across the relatively small study area, suggesting local contrasts in depth and substrate along this part of the Caledonian margin. Here tectonic processes have combined with eustatic changes in sea level to generate a range of heterogeneous environments and associated faunal communities across a relatively small area.

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